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Incipient and Progressive Damage in Polyethylene Under Extreme Tensile Conditions

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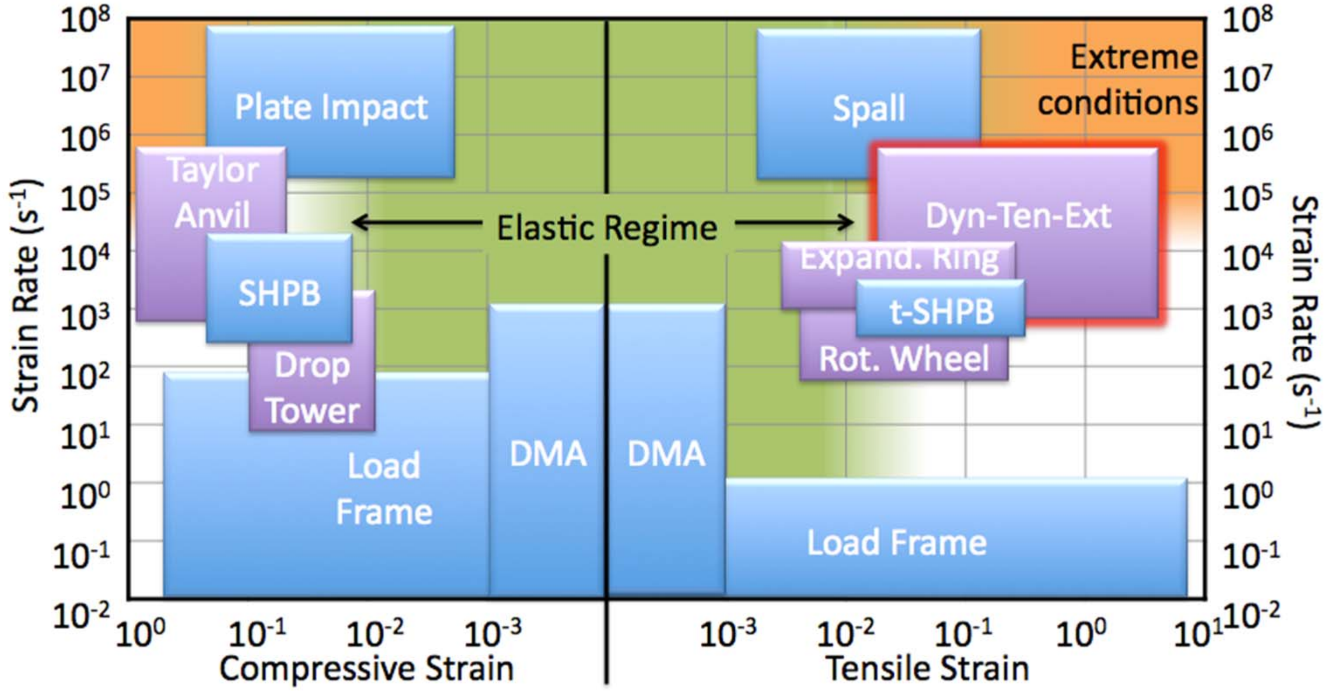
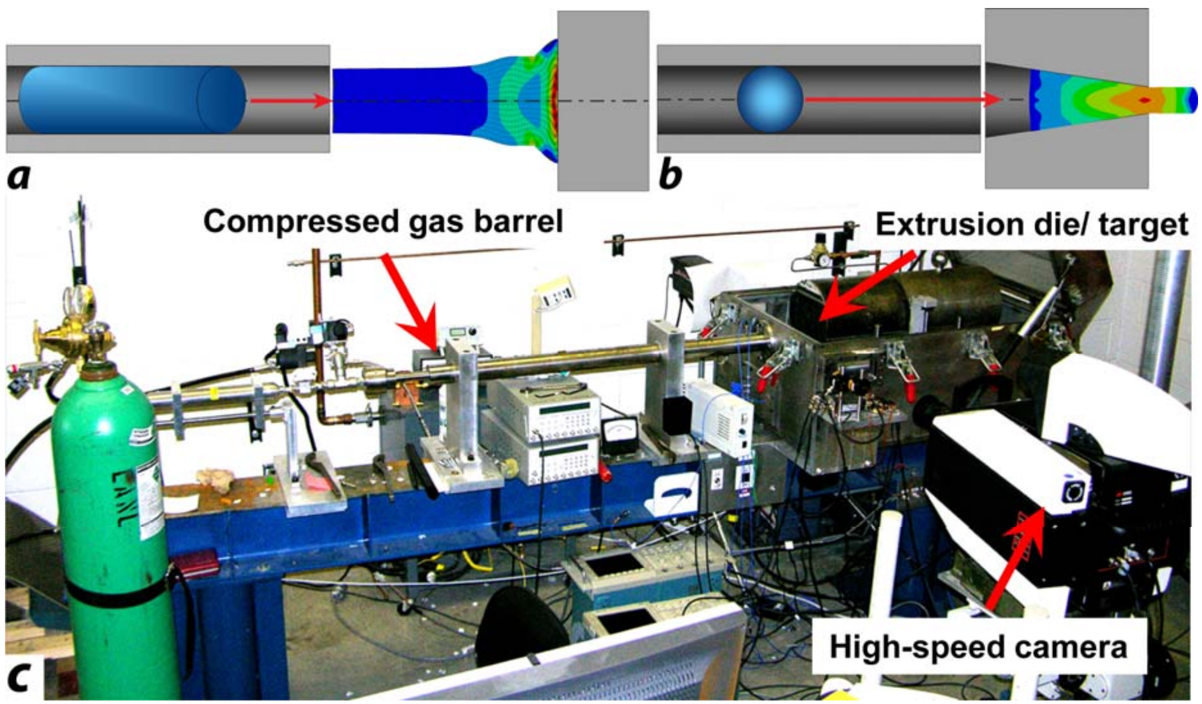
Material characterization is limited by strain and strain-rate



- **Characterization with homogeneous 1-D stress/strain states is typical**
- **More extreme conditions may require integrated testing**

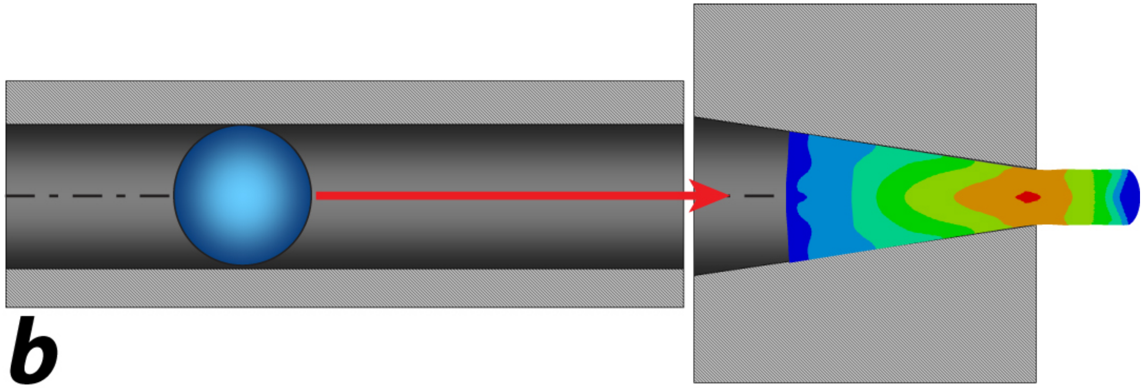
Extreme deformation:
Taylor impact and Dynamic-Tensile-Extrusion

- **Strain >1 with strain-rate>10,000/s**
- **Gradients in strain and strain-rate – rich data for validation**
- **Some damage may be suppressed under compression (pressure)**



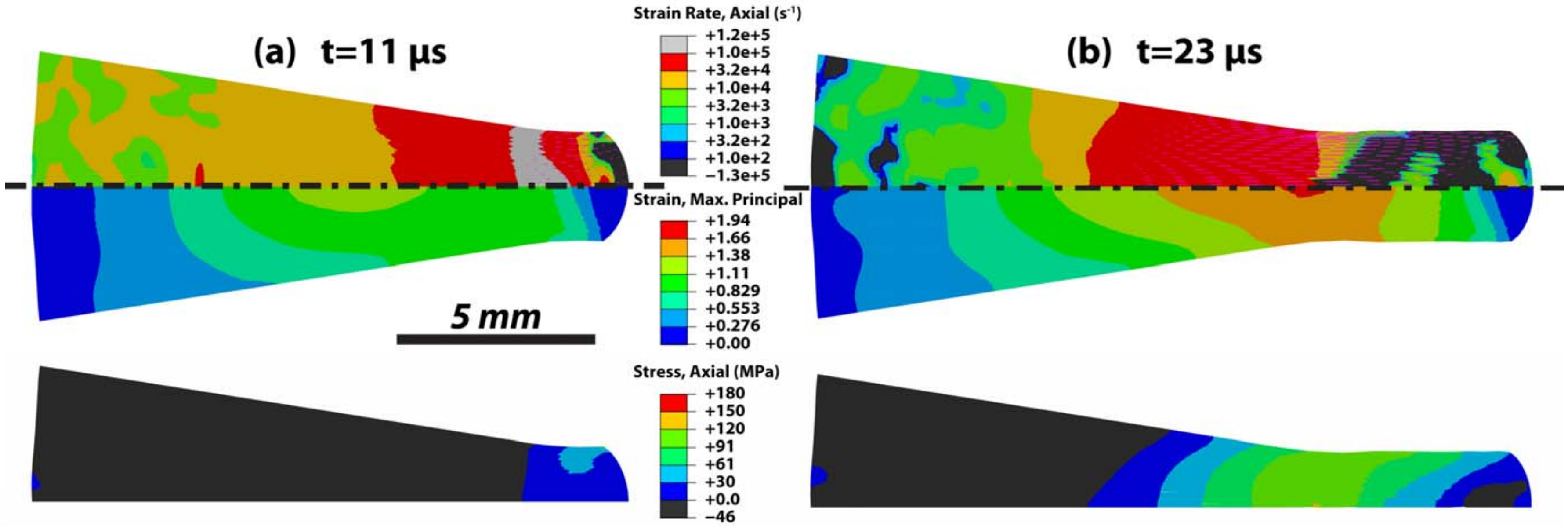
Dynamic-Tensile-Extrusion: Experimental

- **He gas gun accelerated projectile to 300-600 m/s**
- **Conical extrusion – extrusion true strain 1-2**
- **Vary velocity and area reduction to focus on behavior of interest**
  - *Too severe: fragmentation*
  - *Too moderate: no extrusion or pass-through*



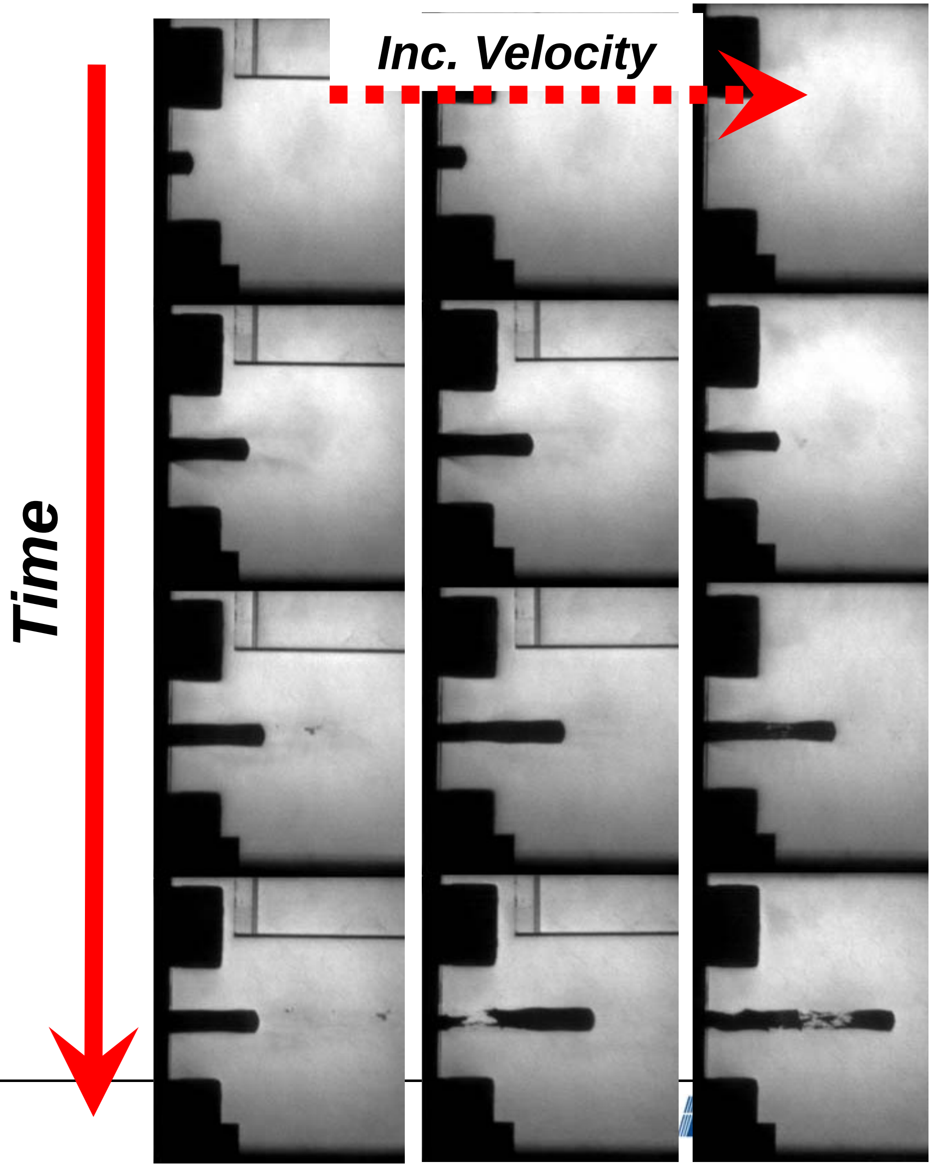
Dynamic-Tensile-Extrusion: Stress/Strain Fields

- **Taylor-validated constitutive model in ABAQUS/Explicit**
- **Simulations demonstrate extreme tensile behavior:**
  - *Strain>1, strain-rate>10,000, axial stress>0 (pressure<0)*



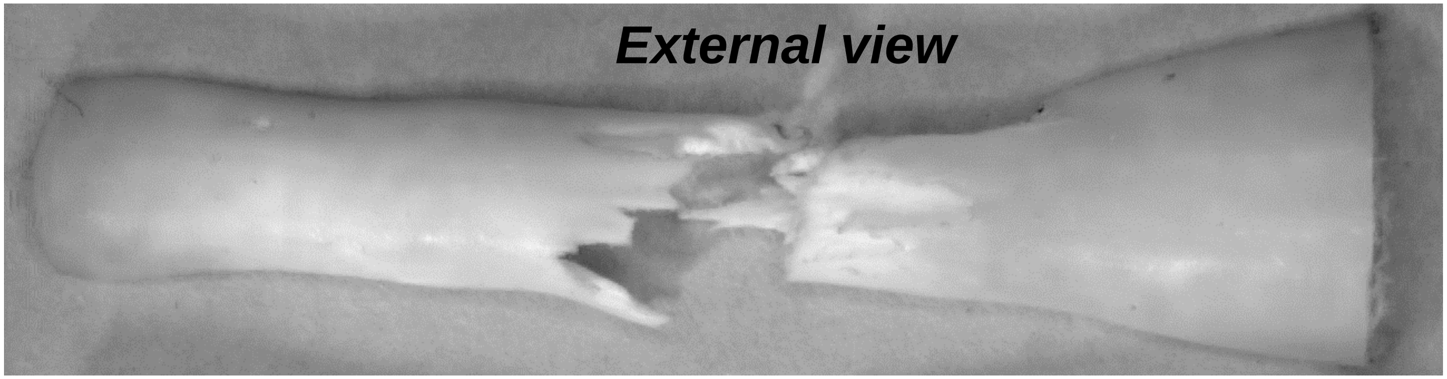
Results: Dyn-Ten-Ext of HDPE

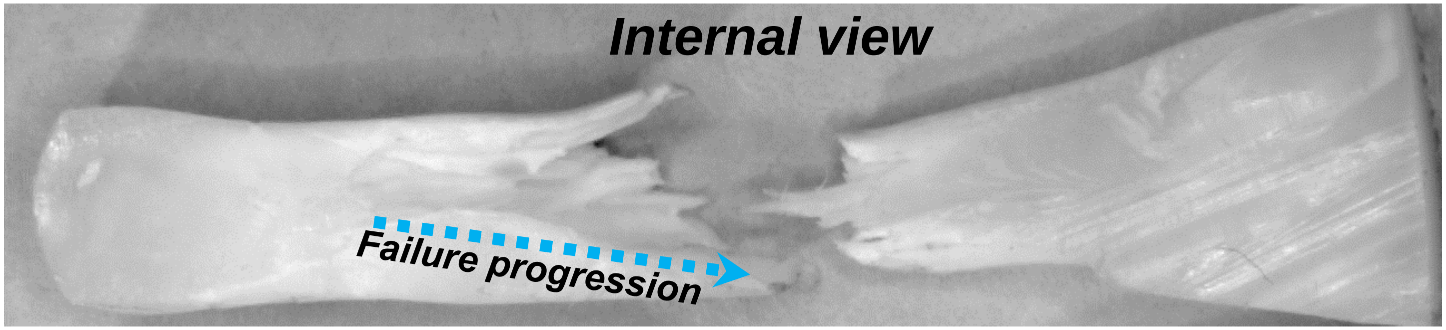
- ***At lower velocities (450 m/s)***, specimen survives and contains sub-critical damage
- ***Intermediate velocities (486 m/s)*** fail in a sequential tensile/shear manner
- ***High velocities (550 m/s)*** fragment at neck catastrophically



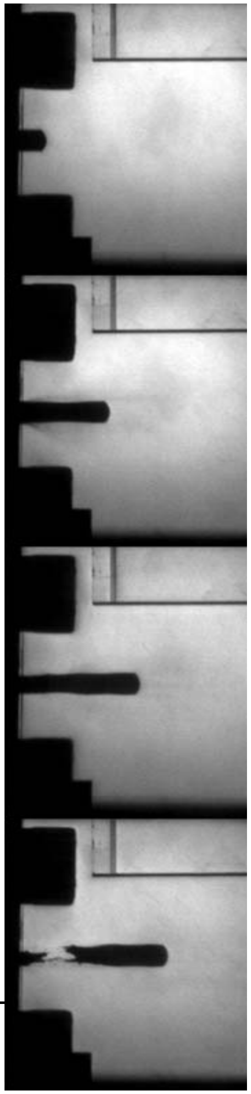
Intermediate velocity: Internal failure, external rupture

- **Internal tensile failure, shear failure, rupture at die exit**



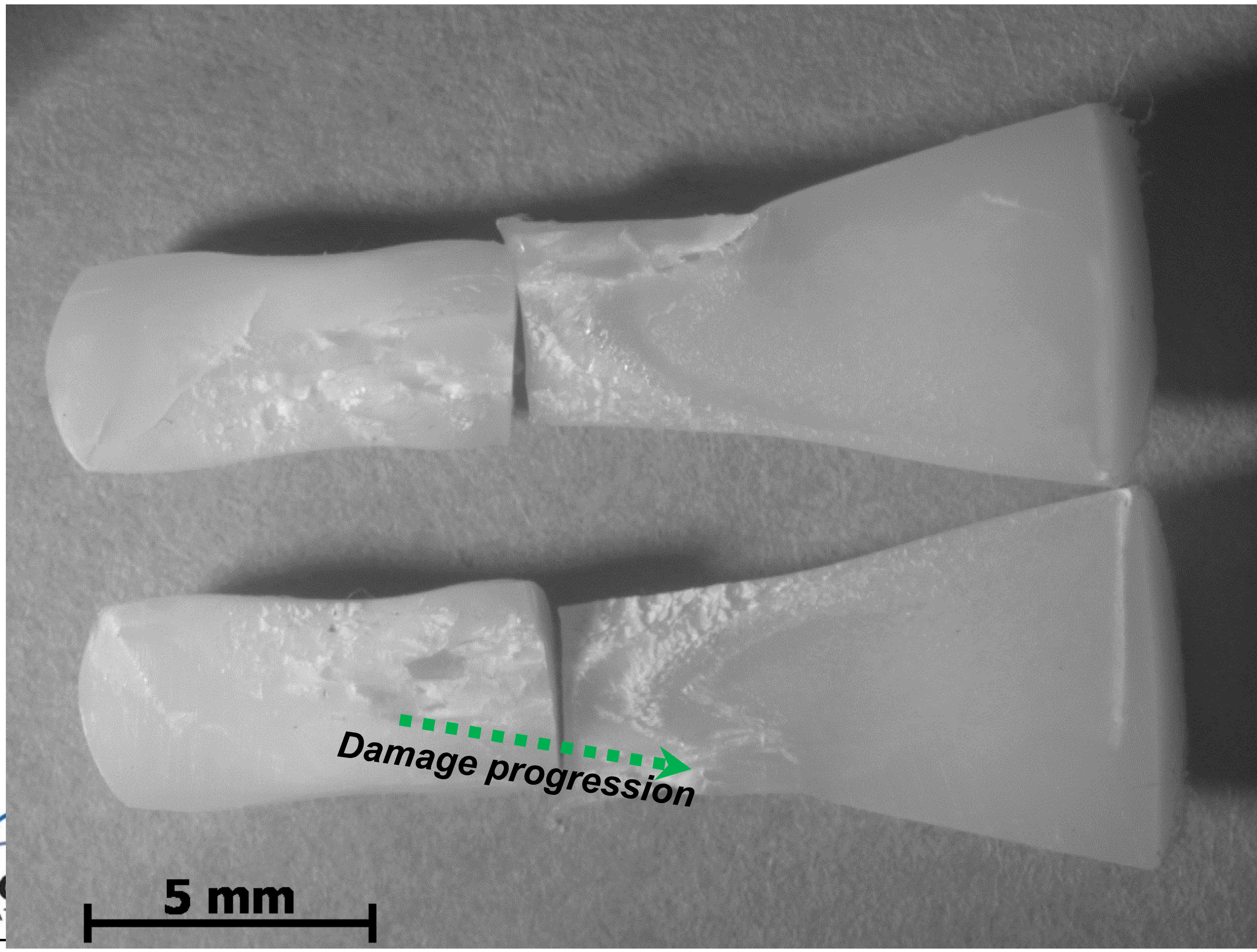


465 m/s

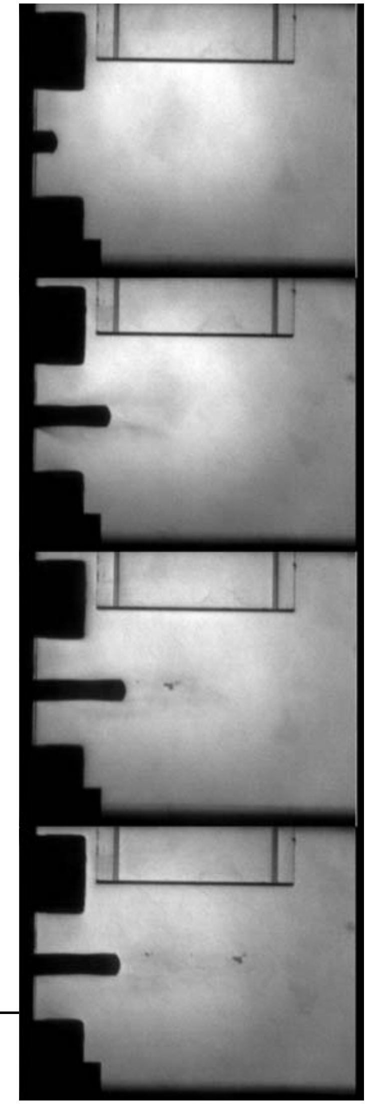


Low velocity: Incomplete failure; incipient damage

- **Internal tensile failure, sheared damage region**

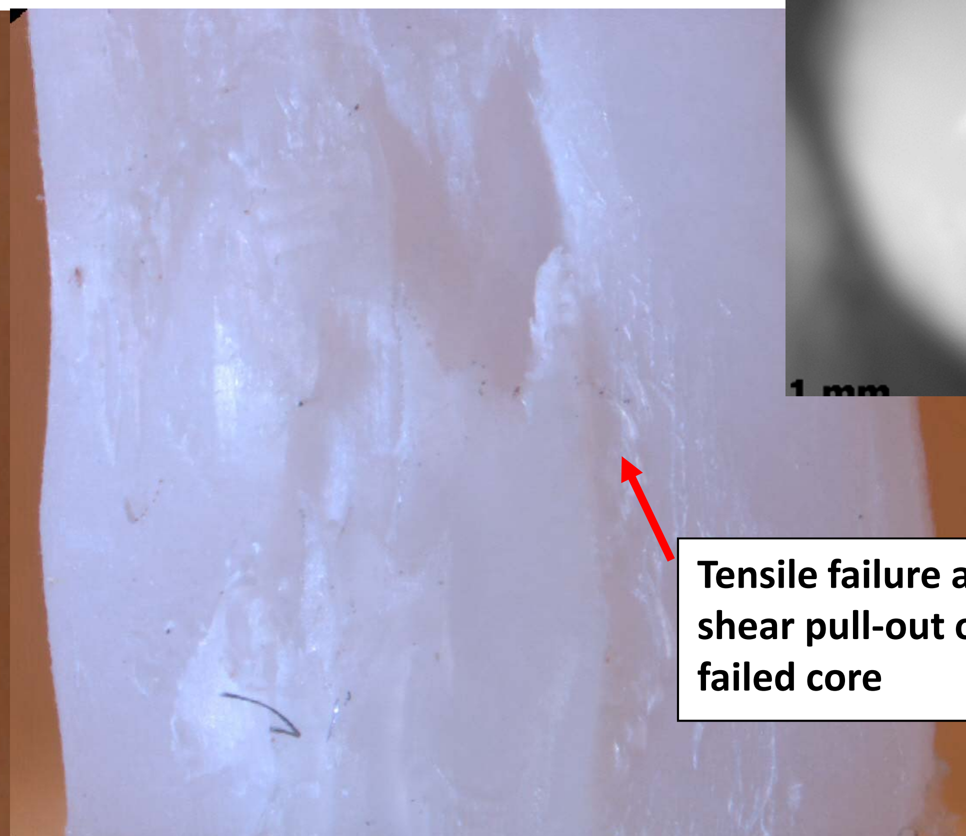


450 m/s

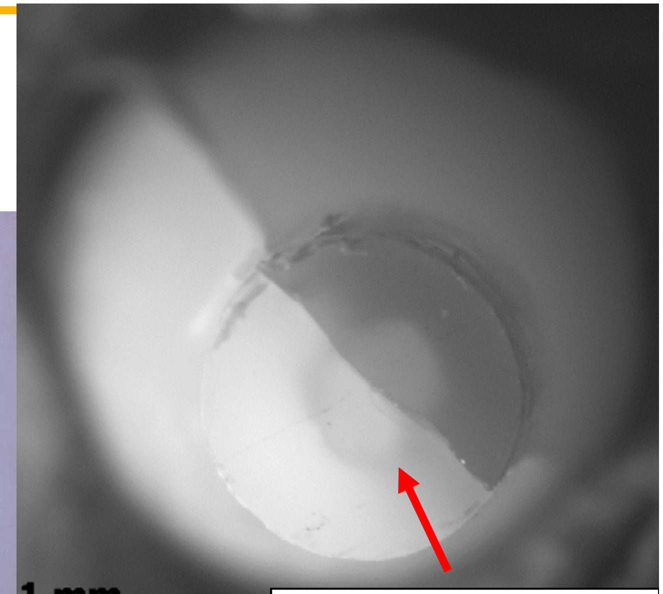


Low velocity: Internal failure; shear damage tube

Chevron rupture, mode-II crack, transition to shear damage field in tube shape



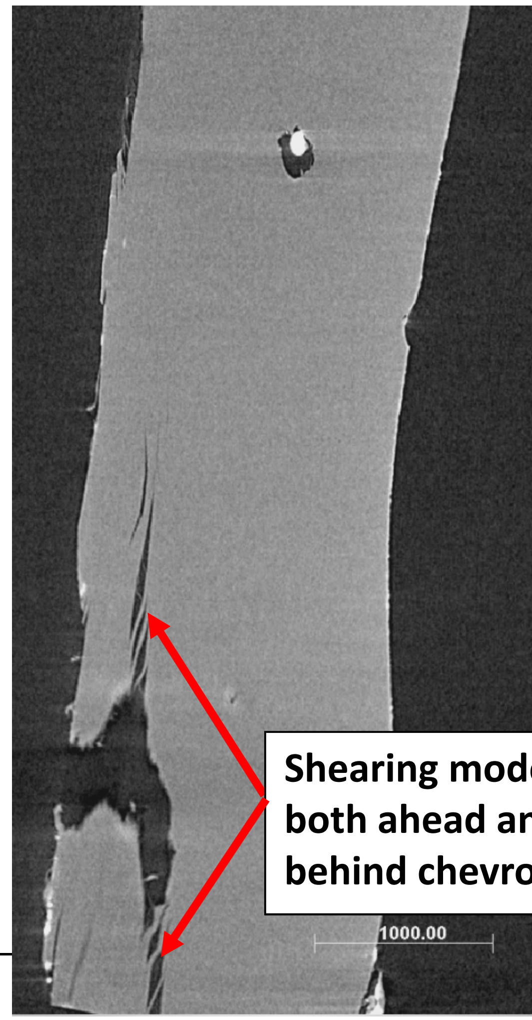
Tensile failure and shear pull-out of failed core

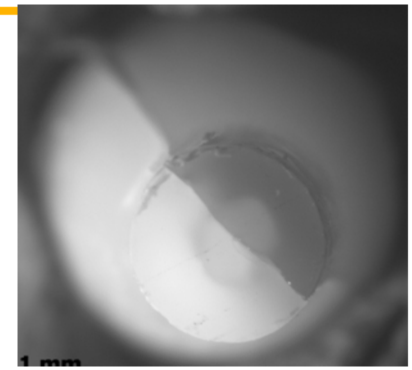


Axisymmetric shear damage "tube"

X-ray CT: Internal failure; shear damage tube

Damage tube is a crack surface bridged by ligaments





Shearing mode crack both ahead and behind chevron

Background on FEA simulations

- **ABAQUS/Explicit dynamic axisymmetric model**
- **Use *rate-temperature equivalence* to shift cold, low rate stress-strain data up to 10,000/s and populate response**
- **Metal plasticity, no damage, adiabatic**
- **Validate dynamics with Taylor impact results**

$$T_{eq}=T_{exp}+A[\log(\dot{\varepsilon}_{eq})-\log(\dot{\varepsilon}_{exp})]$$

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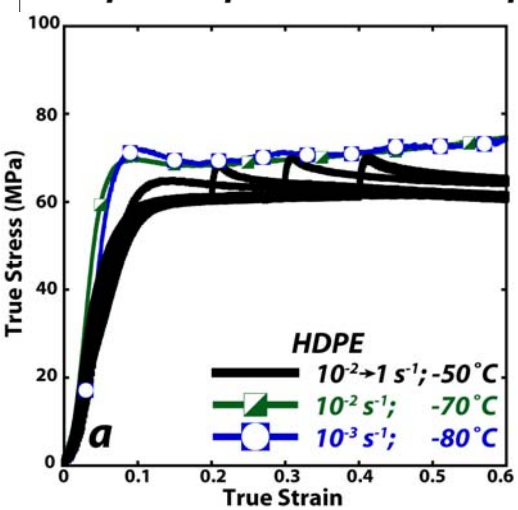
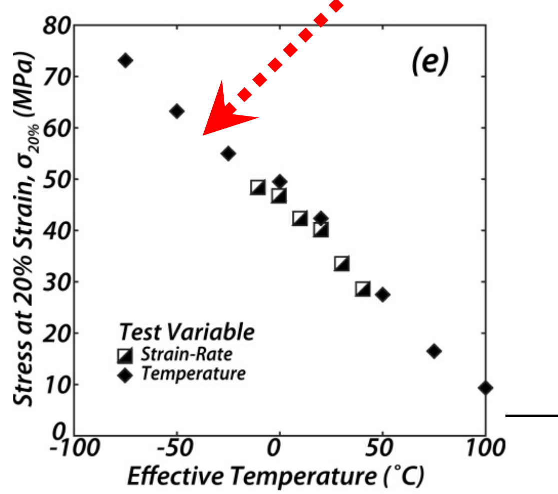
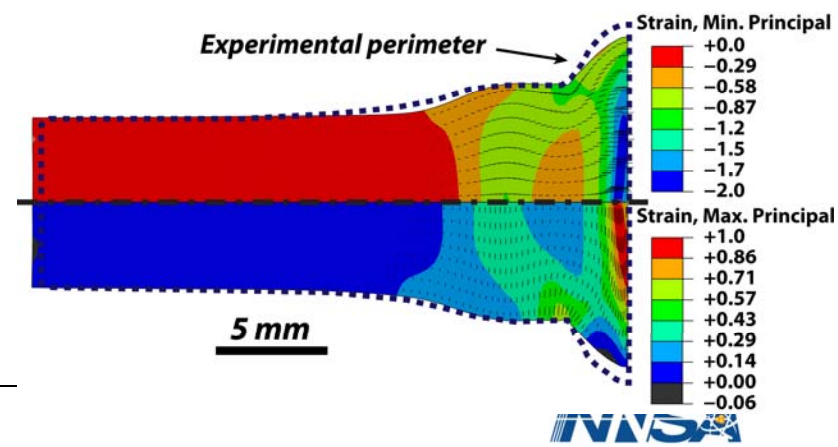
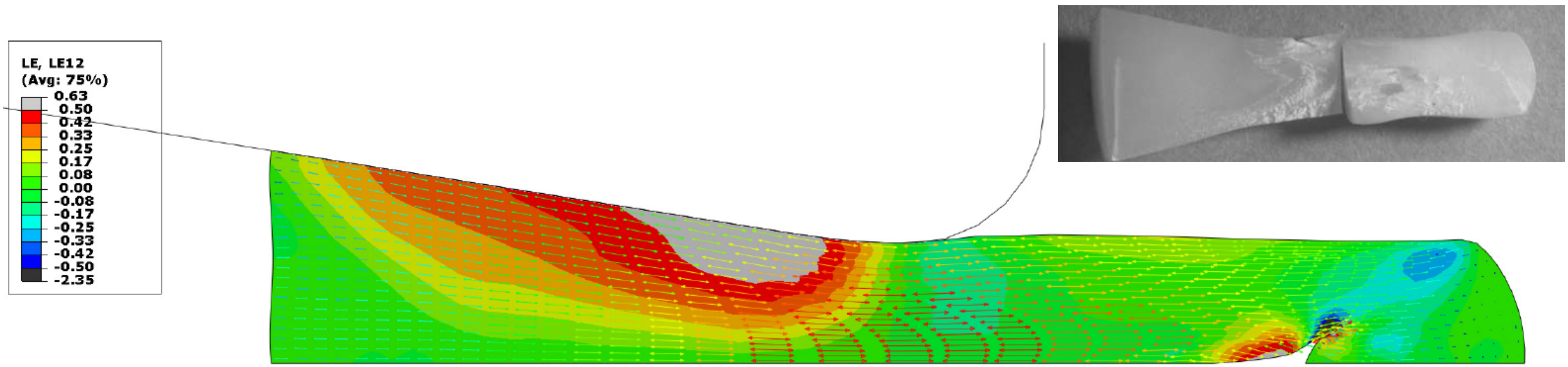


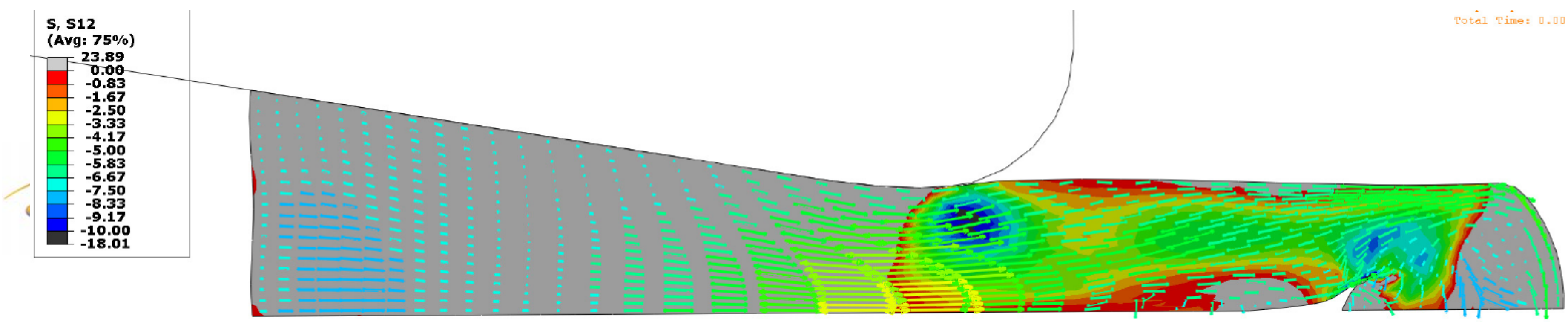




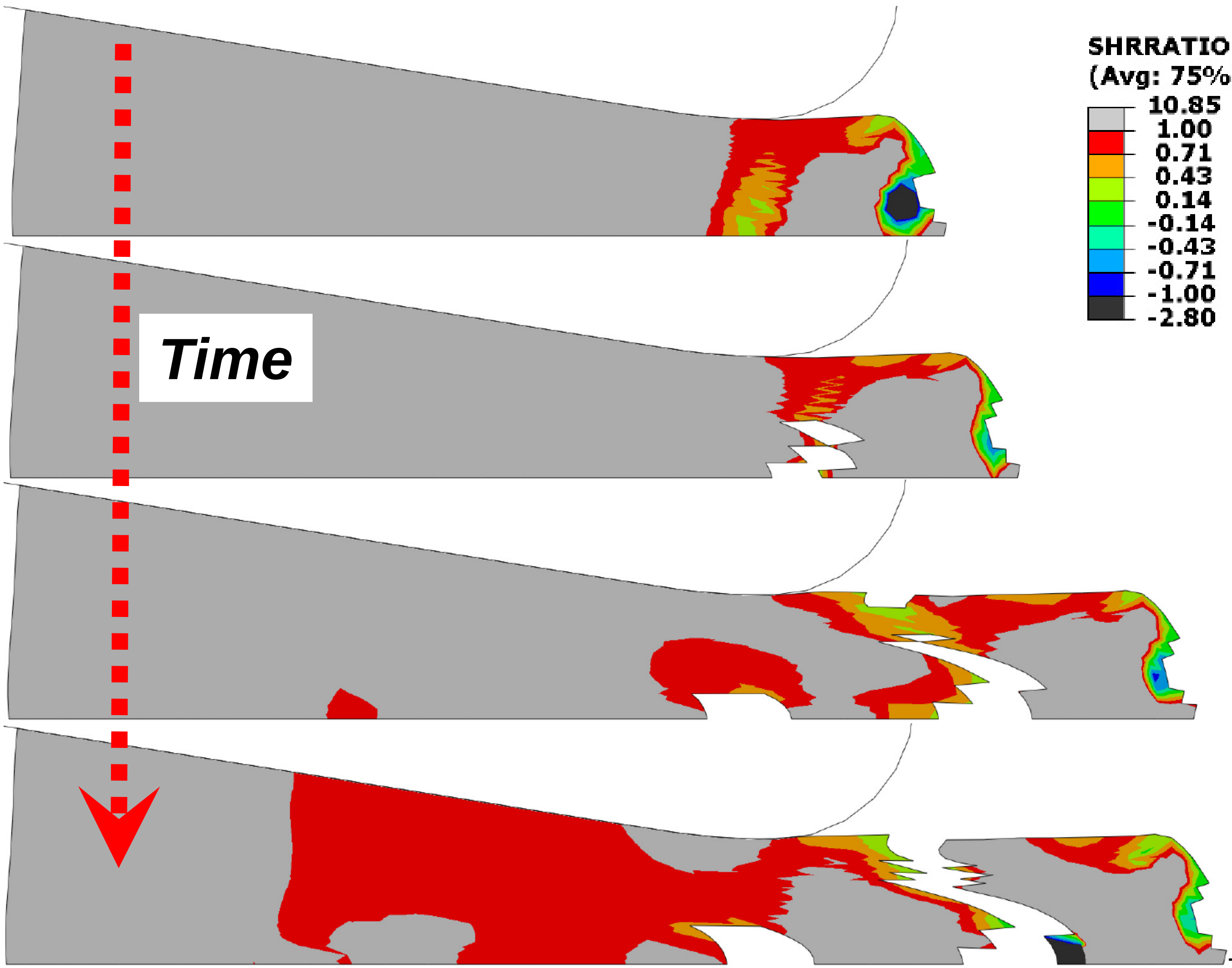
Low velocity FEA: Shear stress localization

- **Terminal strain field does not match damage due to model limitations**
- **Shear stress focus region maps to shear damage zone**
- ***A pressure-shear damage model could yield correct strain field***





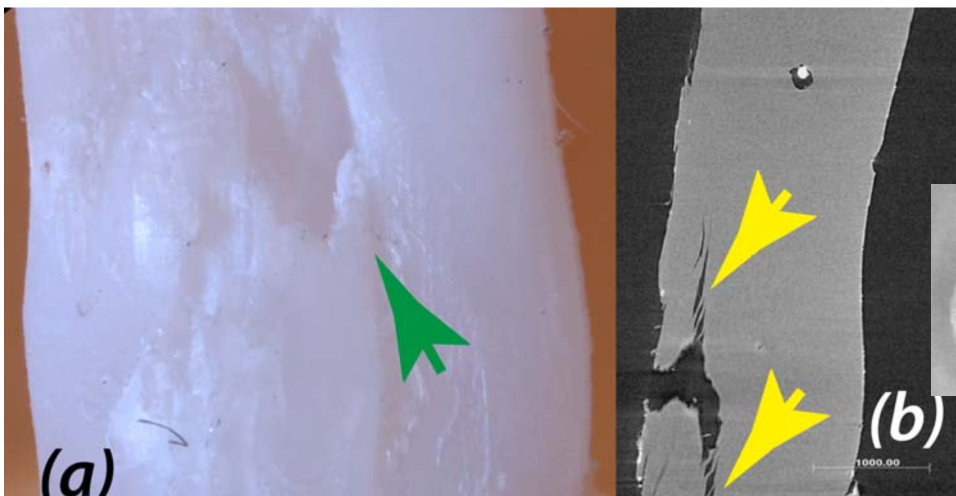
Exploratory results with pressure-shear damage: Failure progression similar to observed path

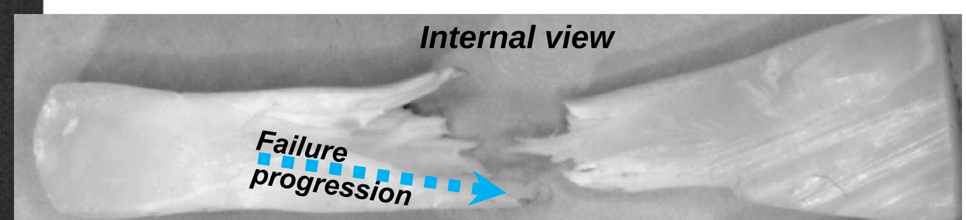


Conclusions

Dynamic-Tensile-Extrusion is an excellent tool for studying dynamic damage in polymers

- **Deformations not accessible by other means, yet simple BCs**
- **Qualitative: map mechanisms with KE and extrusion severity**
- **Focus on incipient and progressive damage for postmortem analysis**

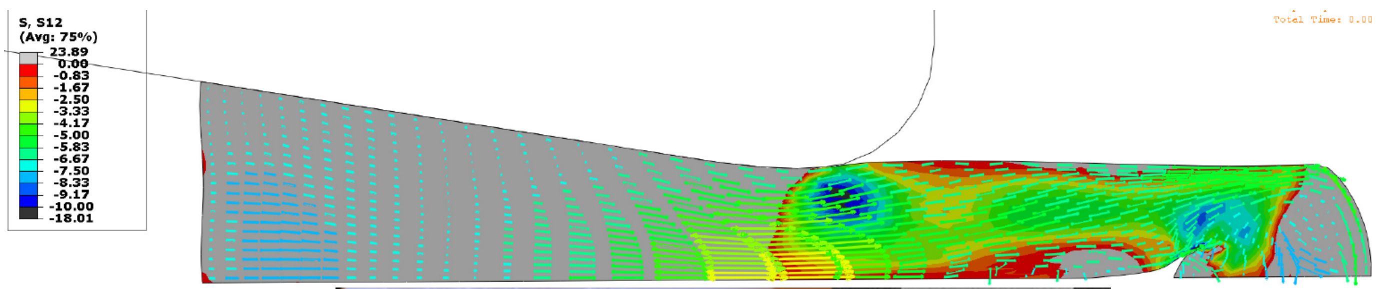


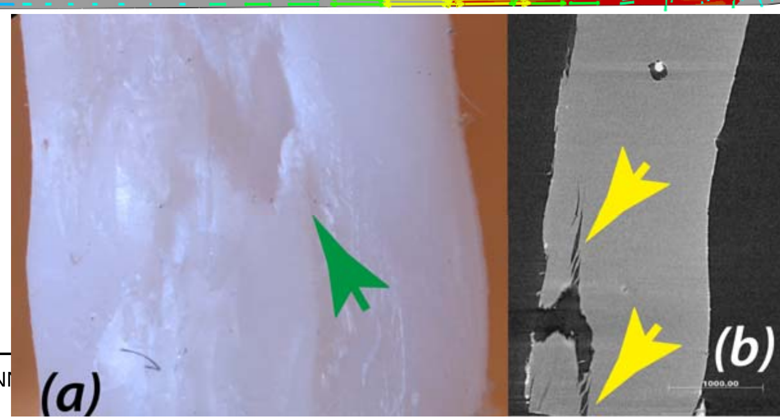


Conclusions

Modeling of continuum deformation in Dyn-Ten-Ext can elucidate mechanisms of damage and failure

- **Infer damage mechanisms by matching path, field localizations**
- **Use to generate hypothetical damage mode and test**
- **Discovery tool, even with limited FEA (e.g., simple constitutive model)**





Abstract

The Dynamic-Tensile-Extrusion (Dyn-Ten-Ext) test was developed at LANL by Gray and coworkers to probe the tensile response of materials at large strains (>1) and high strain-rates (>1000/s) by firing projectiles through a conical die at 300-700 m/s. This technique has recently been applied to various polymers, such as the fluoropolymers PTFE (Teflon) and the chemically similar PCTFE, which respectively exhibited catastrophic fragmentation and distributed dynamic necking. This work details investigations of the Dyn-Ten-Ext response of high density polyethylene, both to failure and sub-critical conditions. At large extrusion ratios (~7.4) and high velocities, such as those previously employed, HDPE catastrophically fragmented in a craze-like manner in the extruded jet. At more modest extrusion ratios and high velocities the specimen extruded a stable jet that ruptured cleanly, and at lower velocities was recovered intact after sustaining substantial internal damage. Thermomechanical finite element simulations showed that the damage corresponded to a locus of shear stress in the presence of hydrostatic tension. X-ray computed tomography corroborated the prediction of a shear damage mechanism by finding the region of partially damaged material to consist of macroscopic shear-mode cracks nearly aligned with the extrusion axis, originating from the location of damage inception.